Carrier Envelope Phase Drift of Picosecond Frequency Combs from an Ultrahigh Finesse Fabry-Perot Cavity

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Abstract: The carrier envelope phase shift of a stacked picosecond pulse train for Compton scattering experiments have been measured to an accuracy of 80 mrad by spectrally resolved interference pattern of a stabilized multiple beam interferometer.
OCIS codes: (120.5050) Phase modulation; (140.3425) Laser stabilization; (320.7080) Ultrafast devices

1. Introduction

Carrier envelope phase (CEP) of light pulses has been known as a physical parameter which is crucial to know and control mainly in experiments in attosecond physics and ultrahigh precision frequency metrology. For pulses longer than 100 fs, the number of optical cycles inside the envelope is higher by a few orders of magnitude, so the CEP is expected to yield no noticeable effects in practice. However, intracavity enhancement of laser pulses is a technique, where high electric field density is created inside a resonant cavity, being typically limited by the damage threshold of the cavity optics. In such experiments a nonlinear crystal or a gas jet is inserted in the cavity to generate frequency converted light and high harmonics [1,2]. High energy electron beam is focused to collide the photon beam thus producing energy upshifted photons (in the X or gamma range) through Compton backscattering [3], which was demonstrated recently also with the help of an enhanced cavity [4].

While the precision of recent methods of CEP drift measurement and stabilization have reached the sub-30 mrad [5], this laser parameter has been virtually inaccessible for a wide range of lasers which do not display sufficient, near octave-spanning spectral width to satisfy the conditions of f-to-2f or 0-to-f interferometries [6,7]. Most recently a linear method of CEP drift measurement has been proposed and demonstrated [8] to overcome the restrictions of laser pulse parameters.

In this paper we demonstrate that the CEP drift of a stacked picosecond pulse train from a high finesse Fabry-Perot Cavity (FPC) can be measured to high accuracy with sufficient speed by a stabilized length multiple beam interferometer (MBI).

2. Experiments

The laser was a customized commercial Ti:sapphire mode-locked oscillator (MIRA from COHERENT Inc.), delivering 2 ps pulses (FWHM) at a repetition rate of 76.4 MHz. In the cavity enhancement setup, the 2-mirror FPC has two identical concave mirrors located two meters from each other in a vacuum chamber. The mirrors provide a finesse of 28000 and a potential power gain of 10000. A feed-back system has been developed to lock the oscillator round trip time to length of the ultrahigh finesse FPC (this feedback is not shown in Fig. 1).

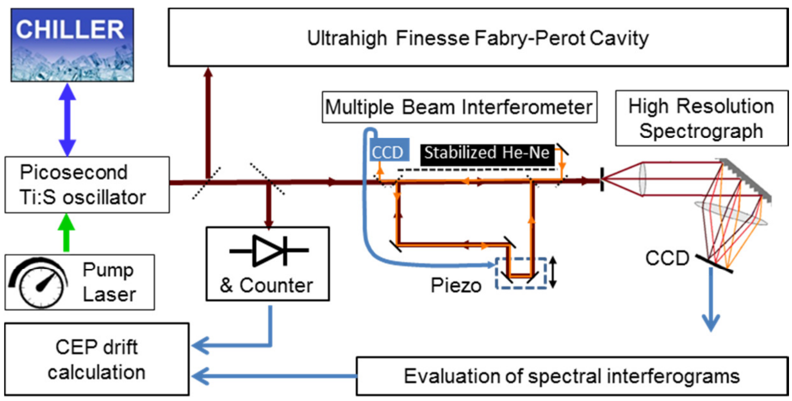

Fig. 1. Schematic diagram of experiment

In our setup (Fig.1), the CEP drift of the pulse train was measured by a multiple beam interferometer and a high resolution spectrograph. This home-made spectrograph consisted of a 1800 line/mm reflection grating had a magnification of 1 to 10, hence it convinently resolved the laser light of a bandwidth of less than 2 nm. If a pulse train enters the MBI having a base length corresponding closely to the repetition rate of the pulses, then the subsequent pulses form spectral interference fringes at the output. In order to make this interference pattern meaningful, the base length of the interferometer has to be constant over time. This requirement seems to be simple, but hard to achieve due to long optical paths.

For the active length stabilization of the interferometer, we used a frequency stabilized helium-neon laser with a coherence length of few hundred's of meters. The He-Ne beam propagates collinearly with but in an opposite direction to the pulse train inside the ring. The interference pattern is captured by a high speed CCD camera, while the feedback loop drives a small mirror mounted on a light-weight fast piezo actuator. This active stabilization system eliminates all thermal expansion effects as well as the low frequency vibrations [8]. Note, that so far this is the only device which is capable to measure directly the CEP drift of laser pulse train, which has considerably narrower bandwidth than an octave.

The CEP drift of the ps pulse train has been varied by two means. As is known, both the power of the pump laser beam and the temperature of the oscillator Ti:S crystal affect the CEP drift in a monotone way. So, the laser control command and the temperature of the chiller has been changed, which resulted in a relatively slow drift of the CEP.

The pulse train to be characterized was to taken to the MBI from the reflected beam on the input mirror of the FPC. The rest of the beam passed through the FPC and contributed to the locking of the cavity to the oscillator.

3. Results

Upon the measurement, the CEP drift of the pulse train was directly measured by the MBI and also the signal from the locking electronics has been recorded. At the start of the first measurement (Fig. 2), we increased the temperature of the Ti:S crystal by 10 °C. As it is seen, the CEP drift of the pulse train is slowly changing due to the gradual increase of the temperature, together with the FPC coupling signal. After 700 s the temperature was set back to normal, and both the measured CEP drift and the FPC locking signal returned simultaneously close to the initial values. At the second measurement the oscillator pump power was varyed (Fig. 3). Again, the measured CEP drif values changed simultaneously to the FPI locking signal.

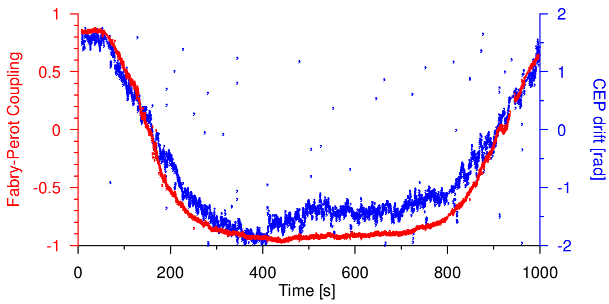

Fig. 2. Increase of the temperature of Ti:S crystal by 10C°.

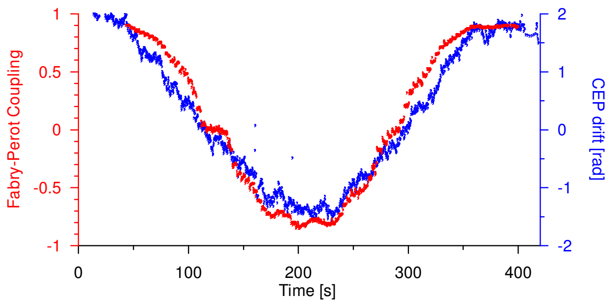

Fig. 3. Changing the pump power of the oscillator

4. Conclusion

We have measured, to our knowledge the first time the carrier envelope phase drift of picosecond pulse train stacked in a ultrahigh finesse Fabry-perot cavity. This may open up the CEP stabilization of mode-locked ps lasers, and hence ensure high resolution comb spectroscopy, intracavity generation of CEP controlled high harmonics, as well as Compton light sources.

5. References

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